Investigating Ceria-Related Defects on SiO_2 Films from Nanoparticle Remnants and Tribofilms

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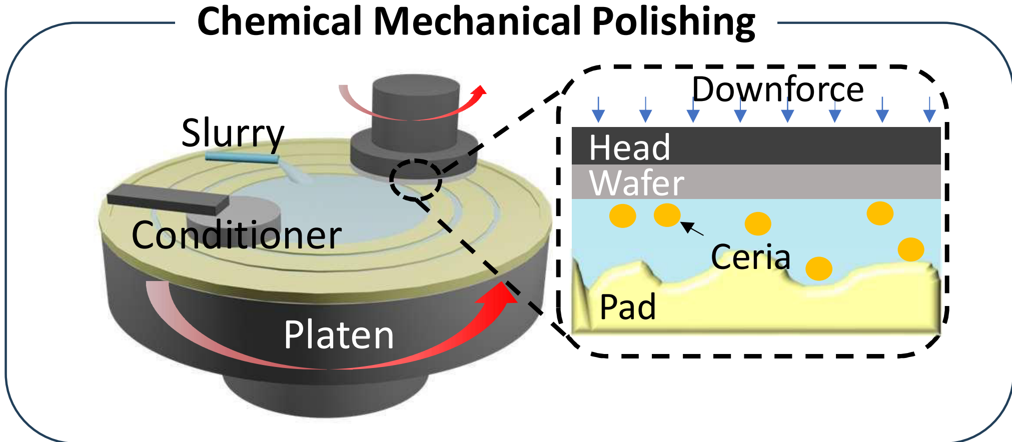
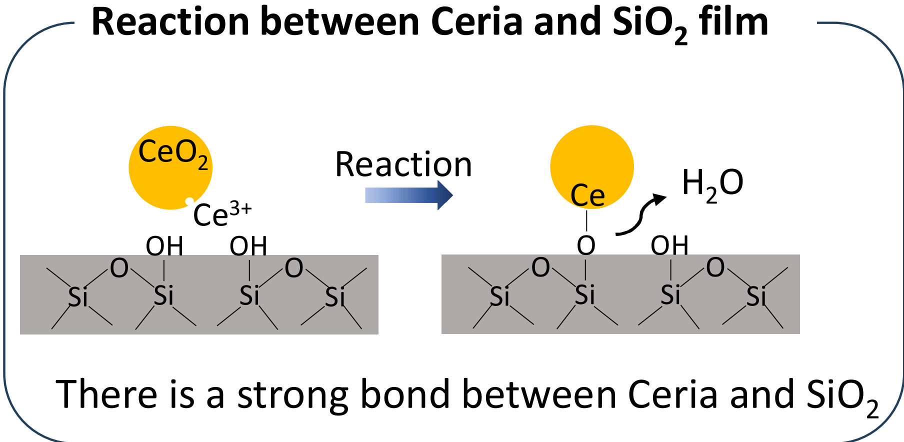
Ceria Defect is the Main Defect in STI-CMP with Ceria-based Slurry

Chemical Mechanical Polishing



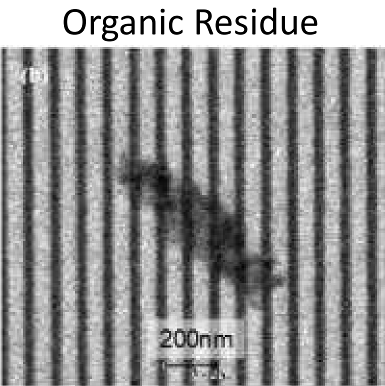
Reaction between Ceria and SiO_2 film



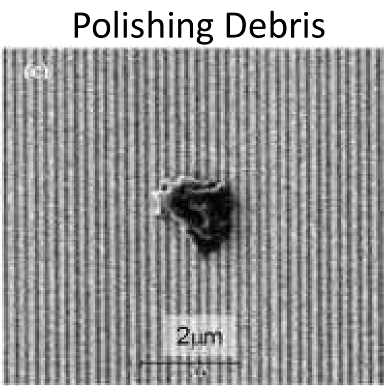
There is a strong bond between Ceria and SiO_2

Defects After Polishing

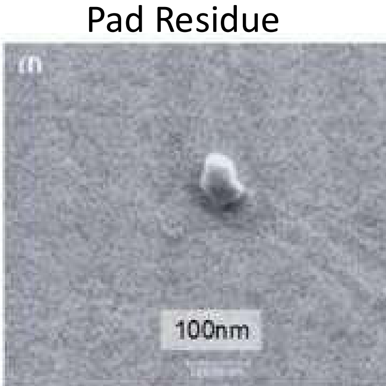
Organic Residue



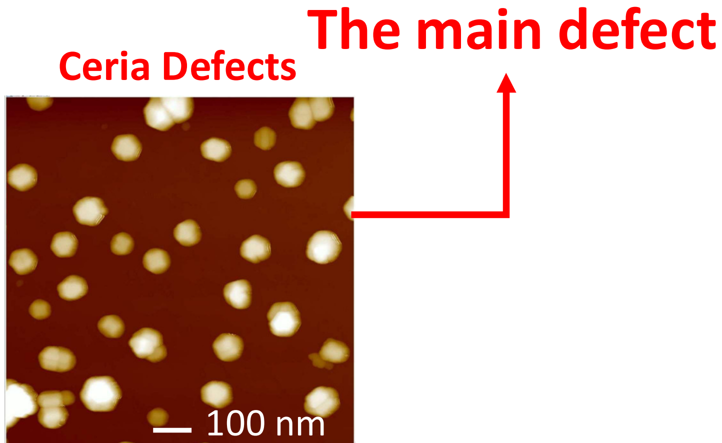
Polishing Debris



Pad Residue



Ceria Defects



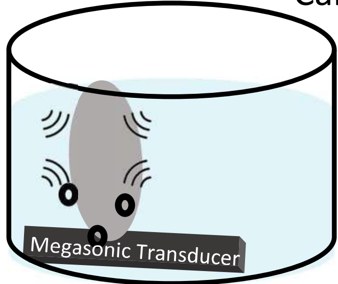
Source: Wei-Tsu Tseng et al., CMP Defect Reduction and Mitigation:Practices and Future Trends ,2021

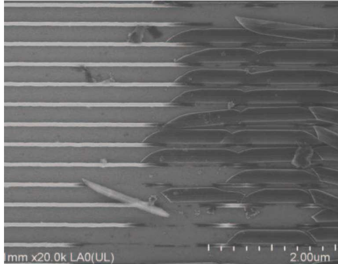
Introduction

Brush Scrubbing is the Most Efficiency Method to Remove Ceria Defects

Megasonic Cleaning

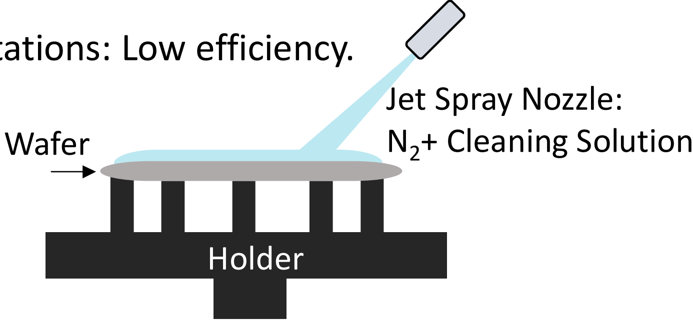
Can damage the smaller features





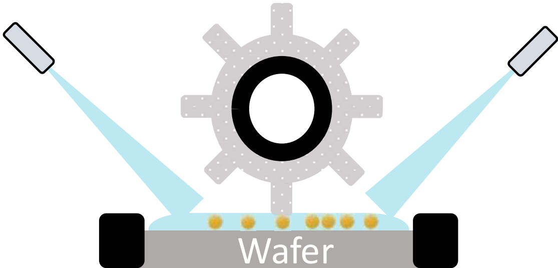
Jet Spray Cleaning

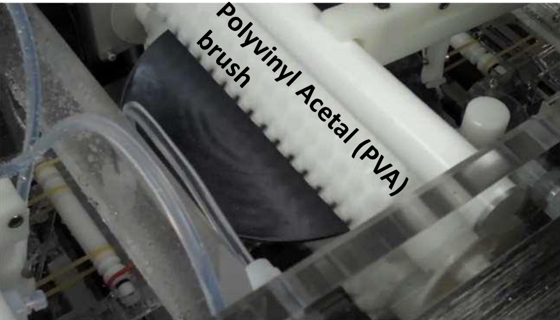
Limitations: Low efficiency.



Brush scrubbing

Brush Scrubbing the high flexibility and direct contact to the wafer to remove Ceria defects.

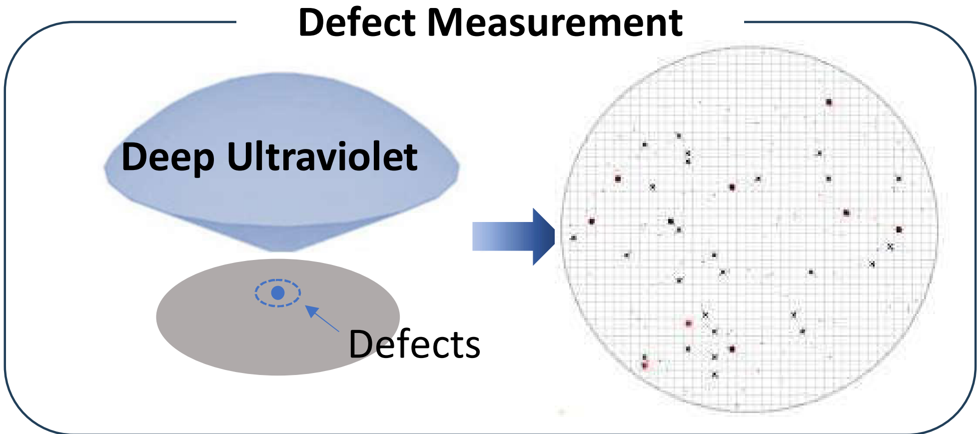


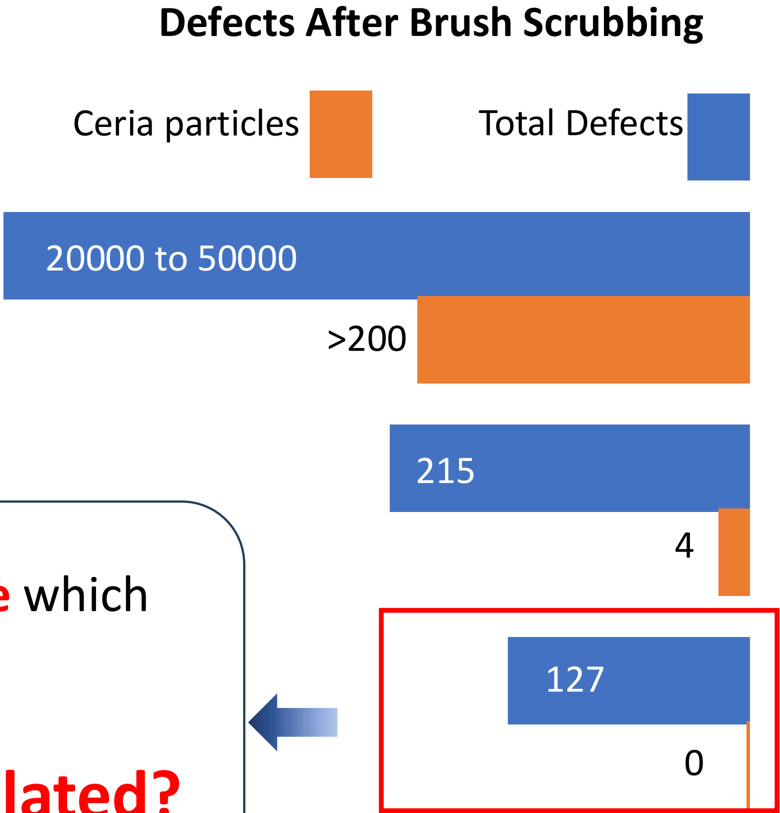


Source: Handbook of Silicon Wafer Cleaning Technology (Third Edition), 2018

Introduction

Challenges in Understanding Defects After Cleaning





Challenges

There **are factors beyond Ceria particles alone** which contributed to the defects.

- Can those factors still be **Ceria-related?**

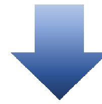
Source: KLA Corporation,
K. Mikhaylichenko, Cleaning Efficiency Improvement Solutions for FEOL CMP, in: The Surface Preparation and Cleaning Conference (SPCC), Portland, 2019.

Introduction

Challenges in Understanding Defects After Brush Scrubbing

Challenges

- There **are factors beyond Ceria particles alone** which contributed to the defects.
- Can those factors still be **Ceria-related?**



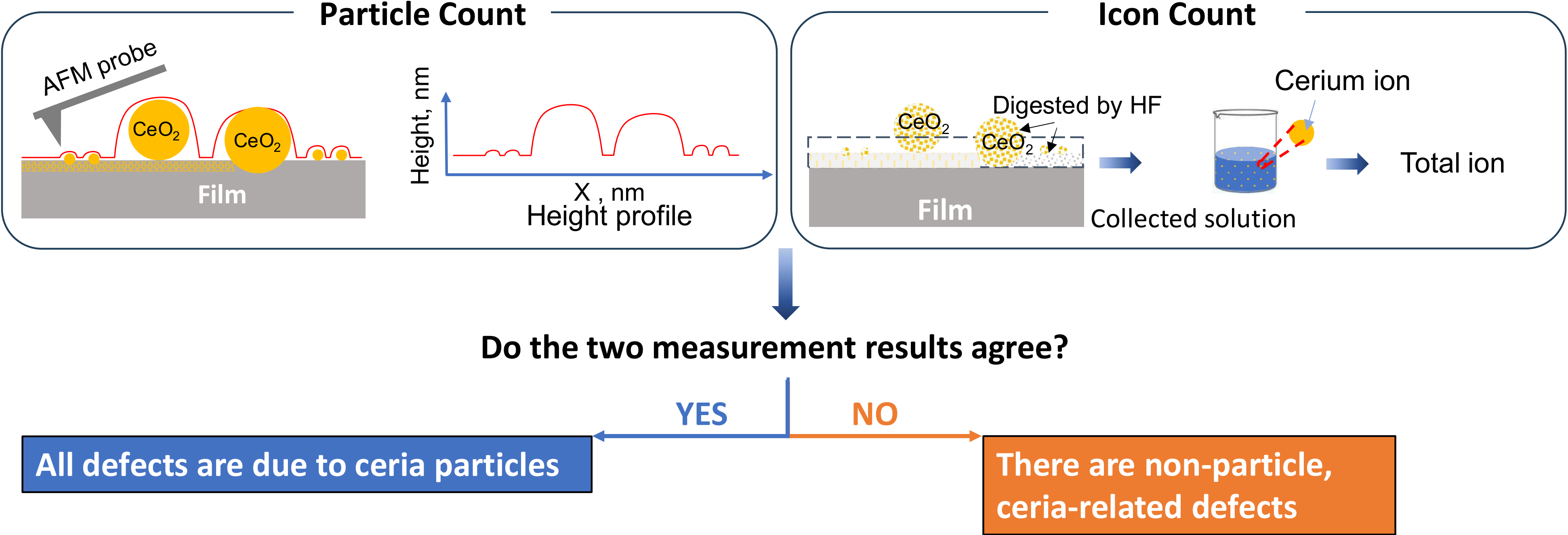
Research Objectives

- Confirm whether there is the presence of Ceria-related defects (Prior Work)
- Examine the hypothesis of Ceria-related defects
- Survey the chemistry properties of Ceria-related defects

Source: KLA Corporation,
K. Mikhaylichenko, Cleaning Efficiency Improvement Solutions for FEOL CMP, in: The Surface Preparation and Cleaning Conference (SPCC), Portland, 2019.

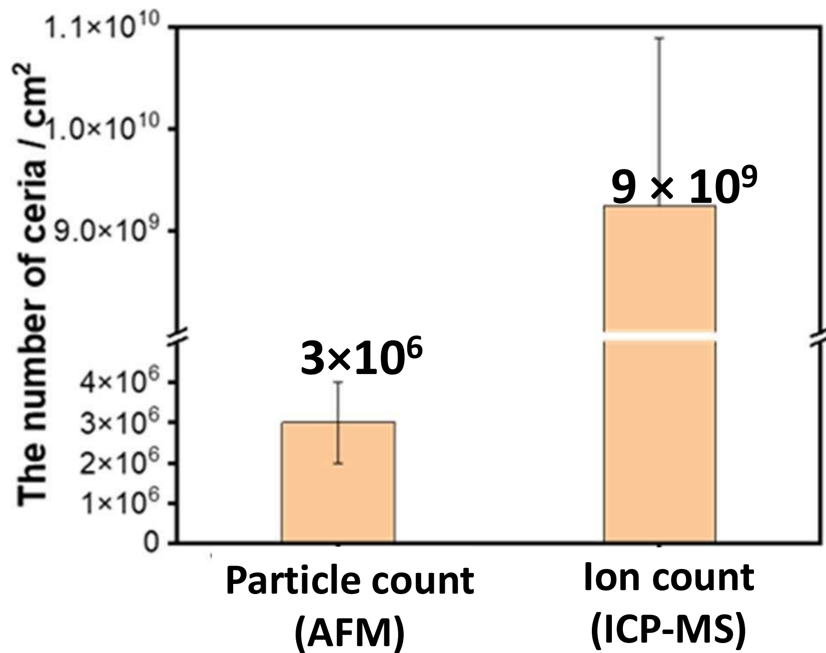
Introduction – Prior Work

Determining Whether Defect Factors Are Still Related to Ceria



Source: Systematic root cause analysis of ceria-induced defects during chemical mechanical planarization and cleaning. Journal of Manufacturing Processes, 127, 27-34.

The Results of Particle Count and Ion Count



The density of Ceria defects on the film estimated from Ion Count is higher than Particle count **3000 times.**

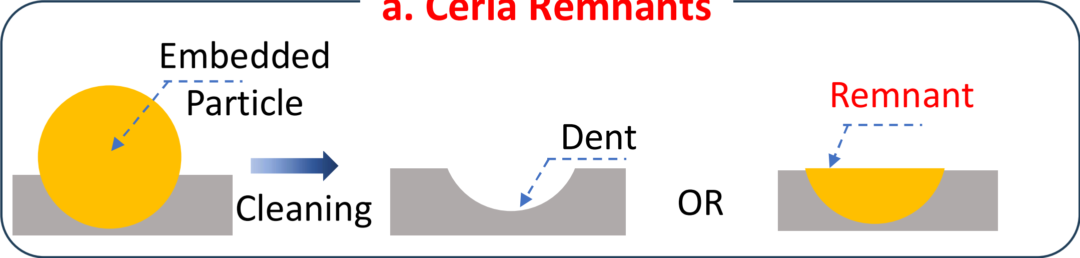
→ This gap suggests the presence of Ceria-related Defects.

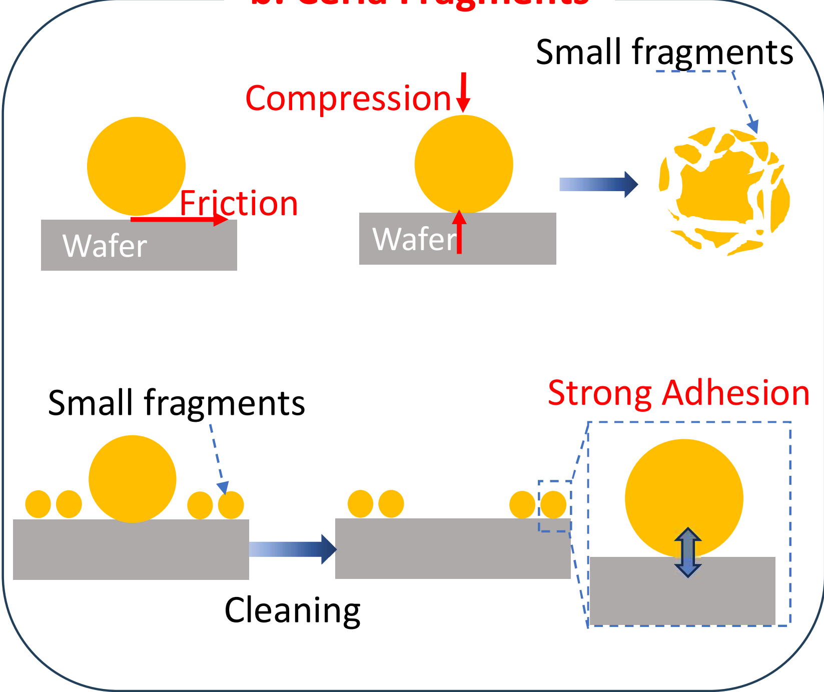
Source: Systematic root cause analysis of ceria-induced defects during chemical mechanical planarization and cleaning. Journal of Manufacturing Processes, 127, 27-34.

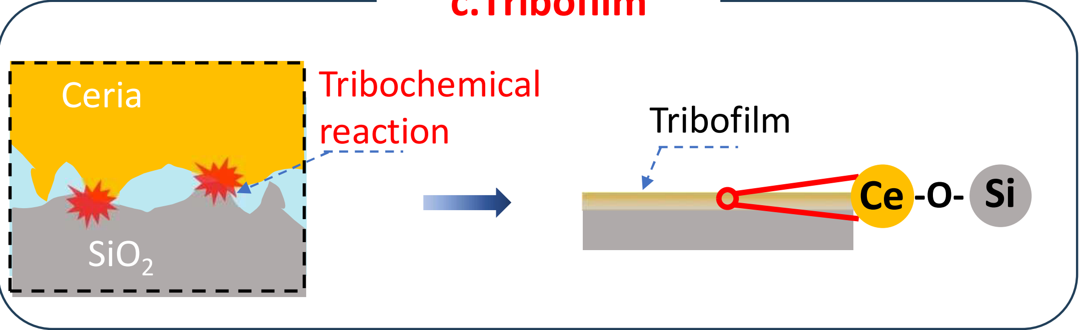
Introduction

Possibilities of Ceria-related Defects

There are three different possibilities of Ceria-related defects.

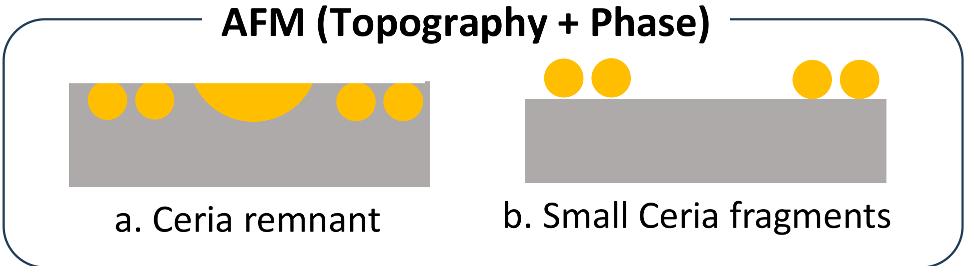


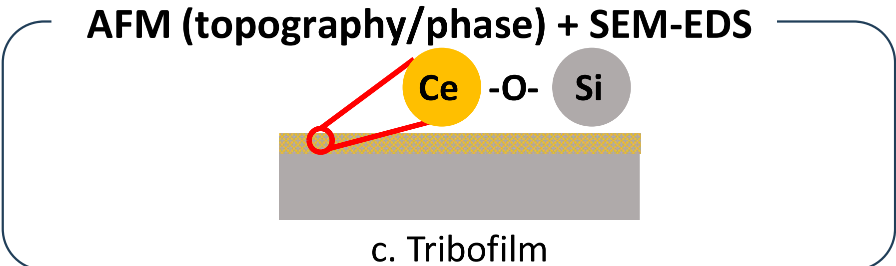


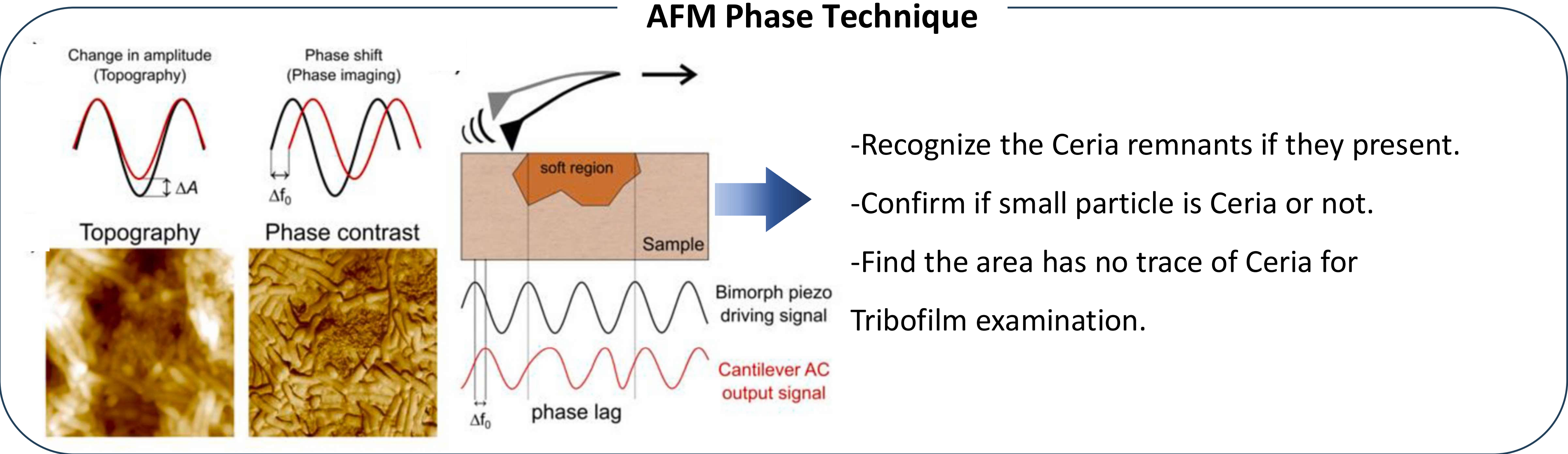


Source: -Mineral Beneficiation: A Concise Basic Course, D.V. Subba Rao, 2011.
- Yan Zhou, Scientific Reports volume 7, Article number: 8426 (2017) Cao, Z., Zhang, X. Measurement of Stress-strain Curves of PECVD Silicon Oxide Thin Films by Means of Nanoindentation. MRS Online Proceedings Library 977, 423 (2006)

Methodologies to Examine Ceria-related Defects





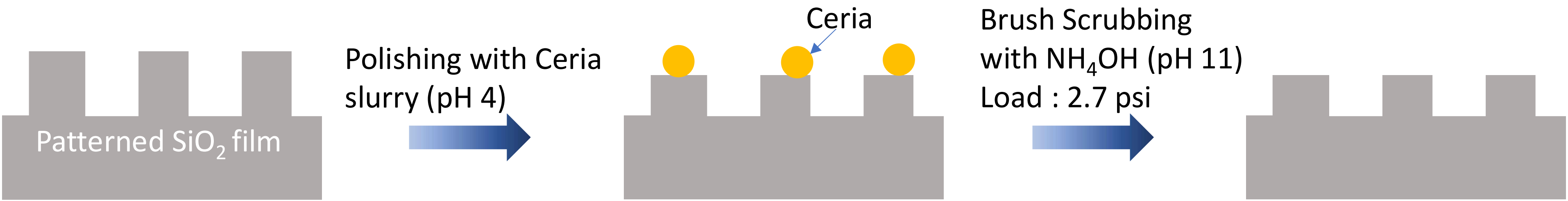


- Recognize the Ceria remnants if they present.
- Confirm if small particle is Ceria or not.
- Find the area has no trace of Ceria for Tribofilm examination.

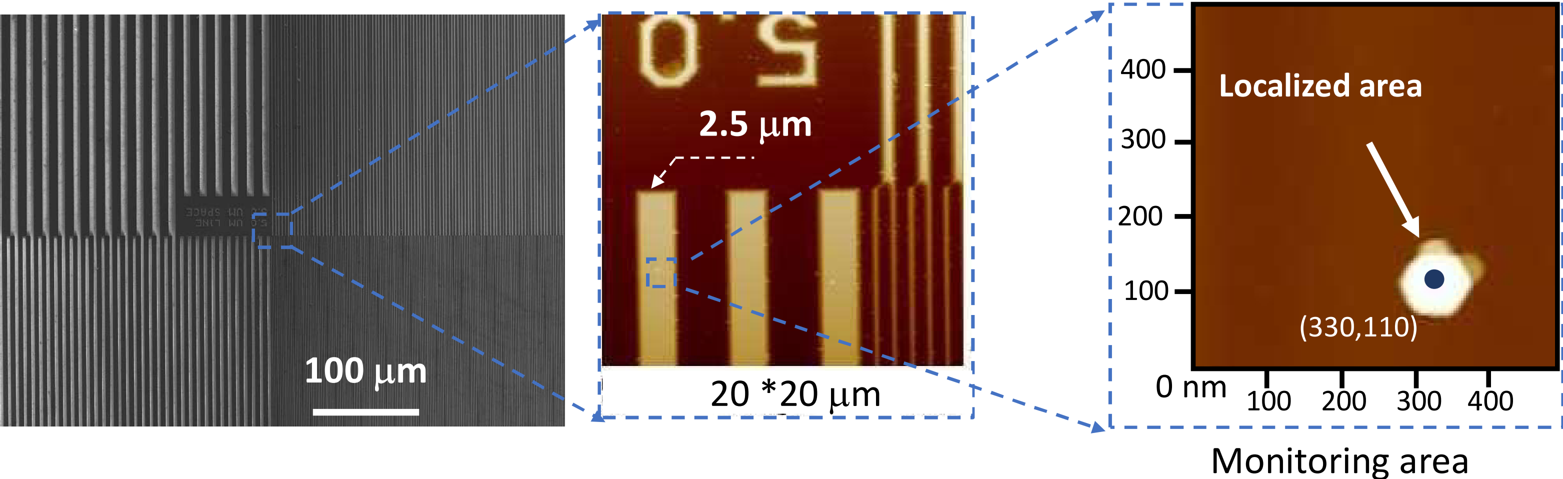
Source: Journal of the Mechanical Behavior of Biomedical Materials Volume 136, December 2022, 105475

Methodology

Sample Preparation



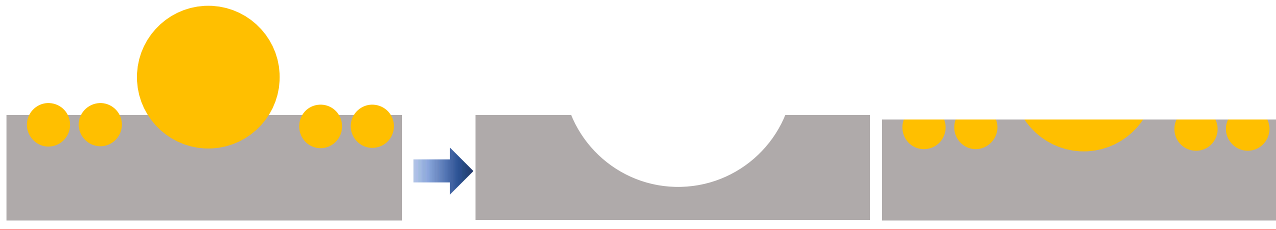
A region with 2.5 μm line/space on pattern film is used to localize position of Ceria-related defects.



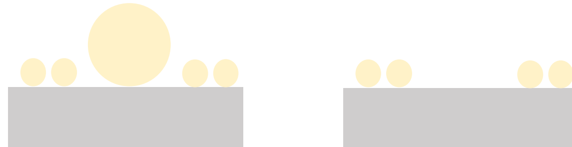
Source: Systematic root cause analysis of ceria-induced defects during chemical mechanical planarization and cleaning. Journal of Manufacturing Processes, 127, 27-34.

Possibilities of Ceria-related Defects

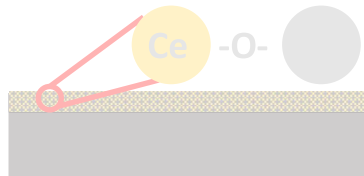
- **a.** Ceria Remnants



- **b.** Small Ceria remaining on the film

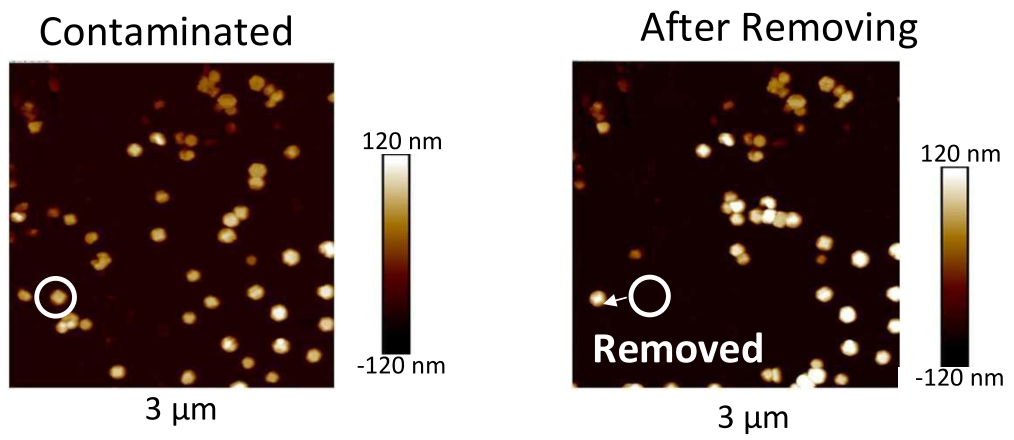


- **c.** Tribofilm

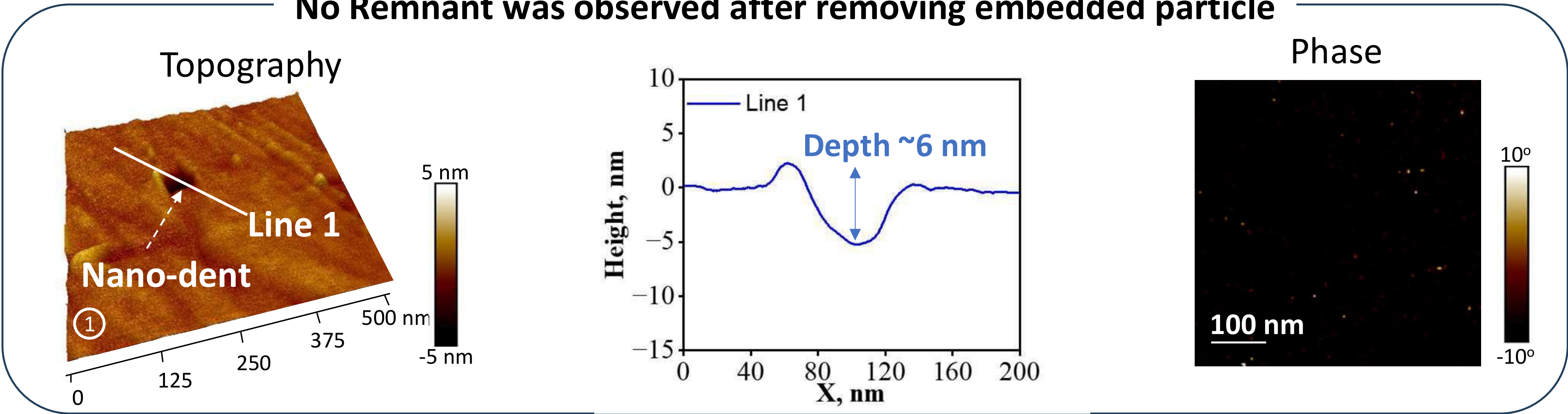


Result - a. Ceria Remnants

The Removal of Embedded Particles Leave Dents Instead of Remnants



No Remnant was observed after removing embedded particle

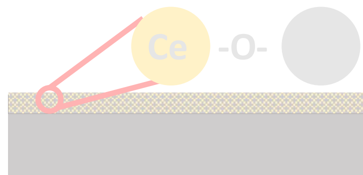


Possibilities of Ceria-related Defects

- **a.** Ceria Remnants

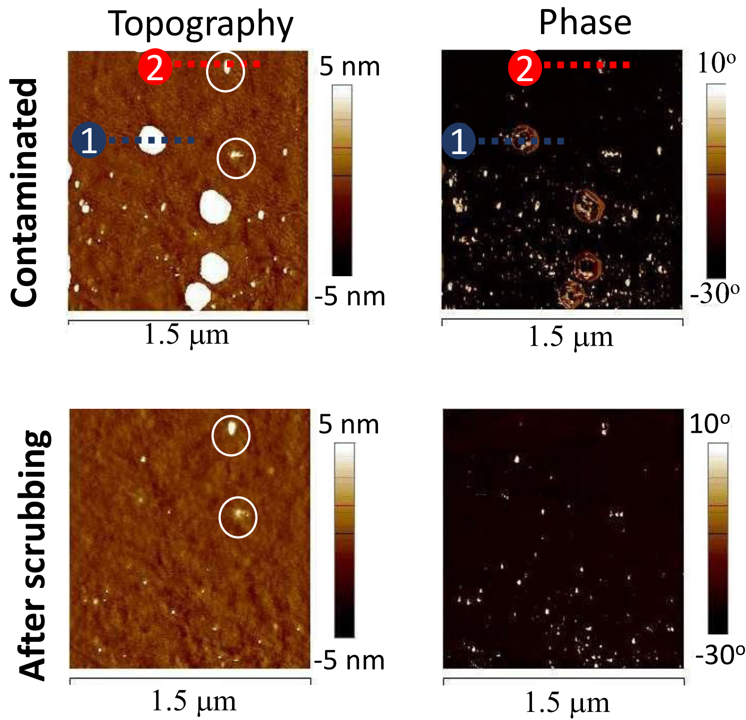
- **b.** Small Ceria fragments remaining on the film

- **c.** Tribofilm

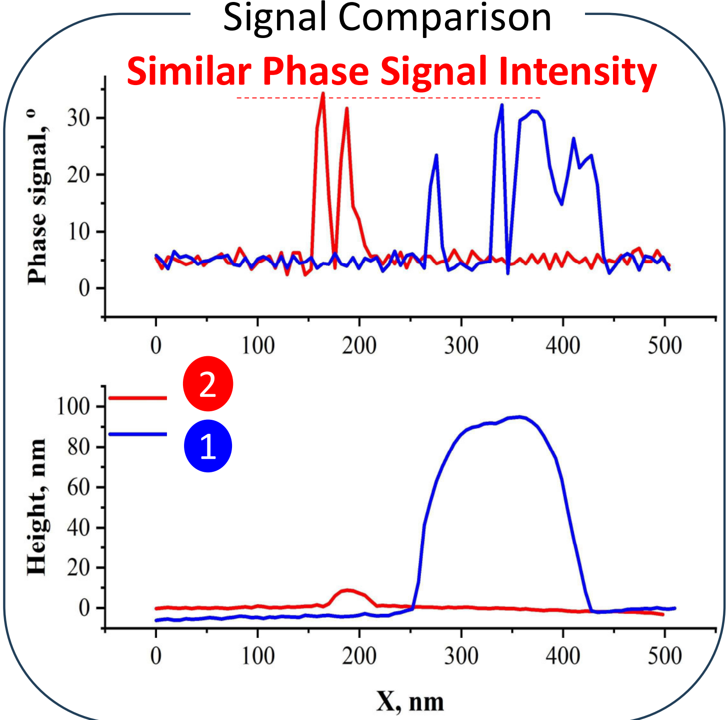


Result – b. Ceria Fragments

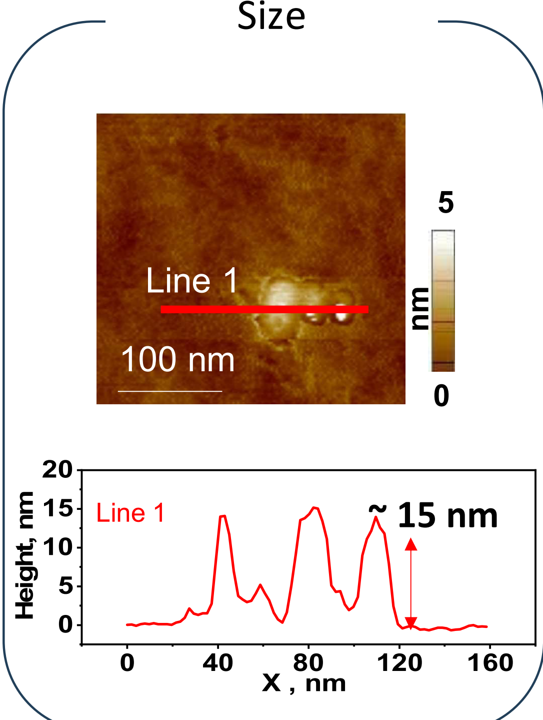
There is the Presence of Small Ceria with the Size of 10 – 15 nm



Small particles persist on the film after cleaning.



Phase Signal confirm small particles are Ceria.

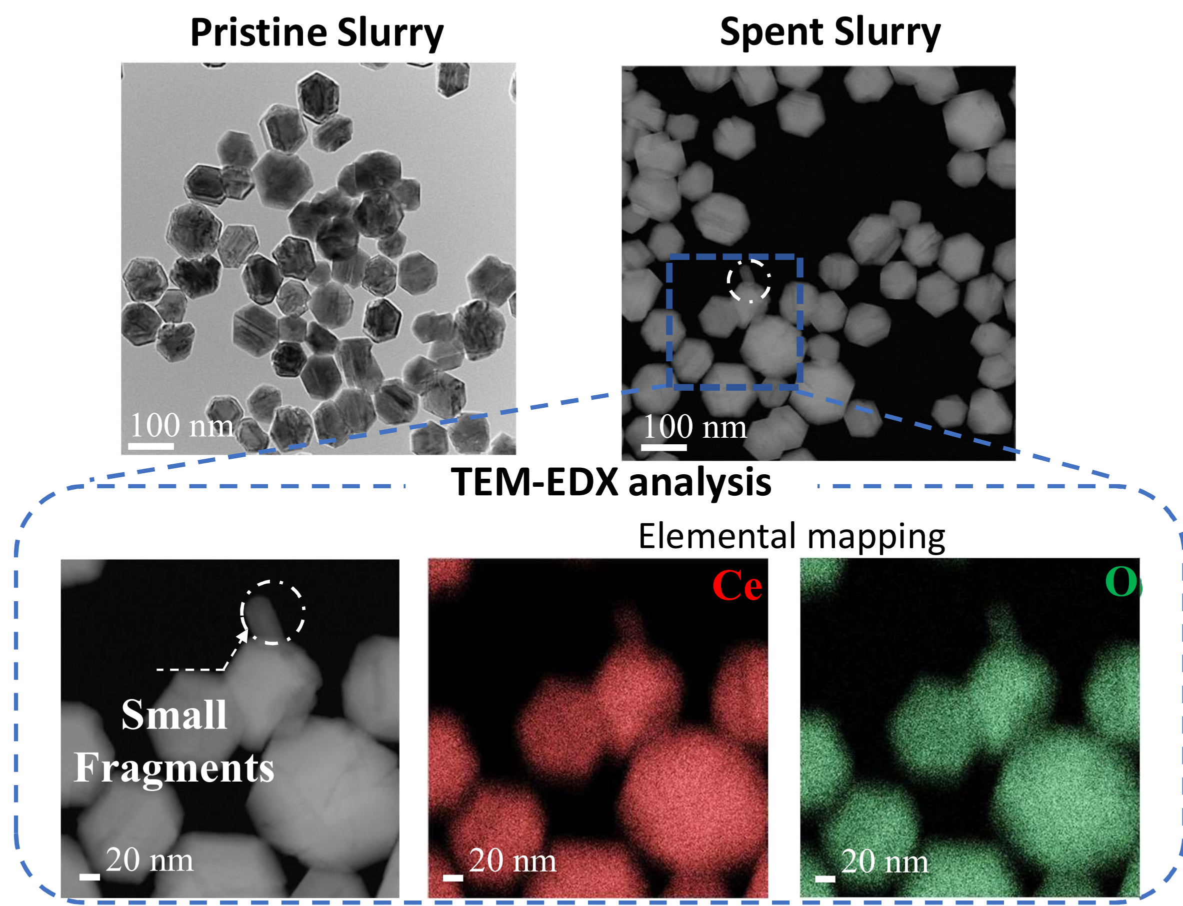


Small Ceria have the size of 10-15 nm.

Source: Systematic root cause analysis of ceria-induced defects during chemical mechanical planarization and cleaning. Journal of Manufacturing Processes, 127, 27-34.

Result – b. Ceria Fragments

Ceria Abrasives Break into Fragments during Polishing

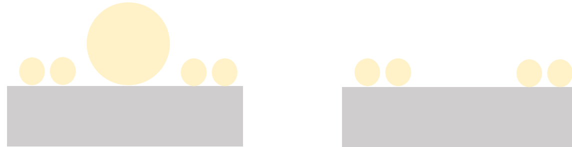


TEM-EDS reveals the presence of broken fragments in the spent slurry, contribution to the Ceria-related defects.

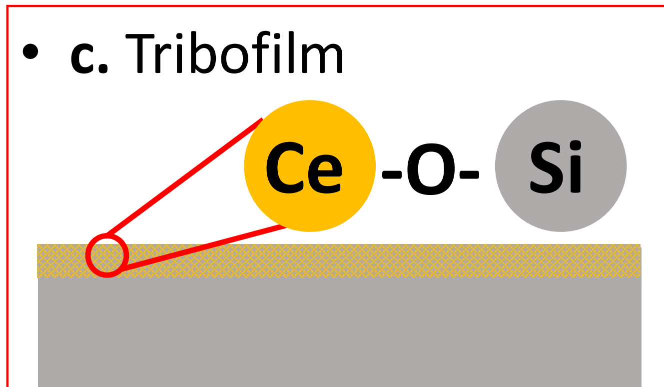
Possibilities of Ceria-related Defects

- **a.** Ceria Remnants

- **b.** Small Ceria remaining on the film

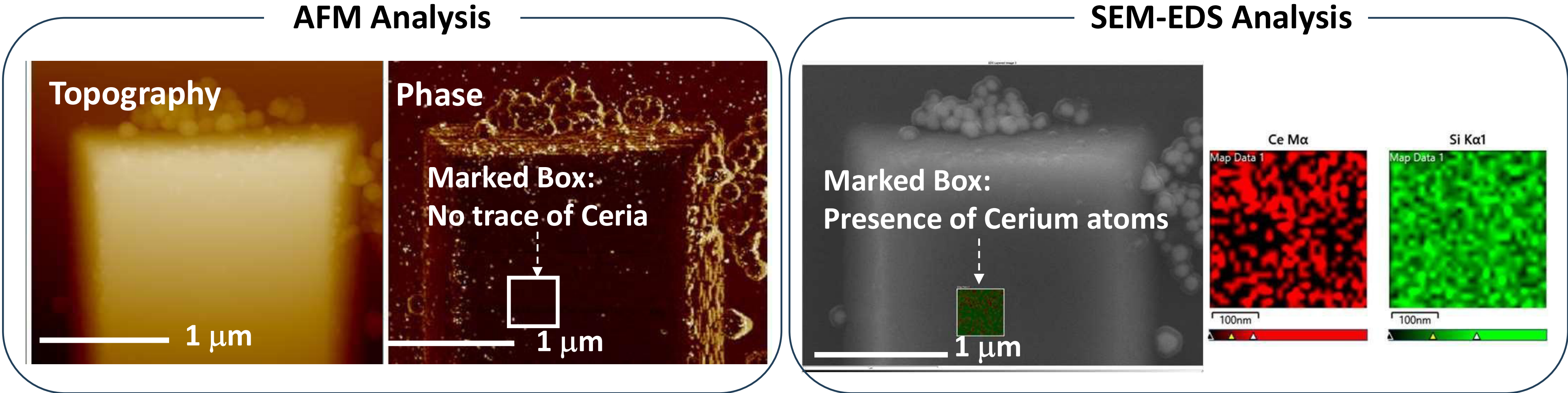


- **c.** Tribofilm



Result – c. Ceria Fragments

SEM-EDS and AFM Reveal the Presence of Tribofilm

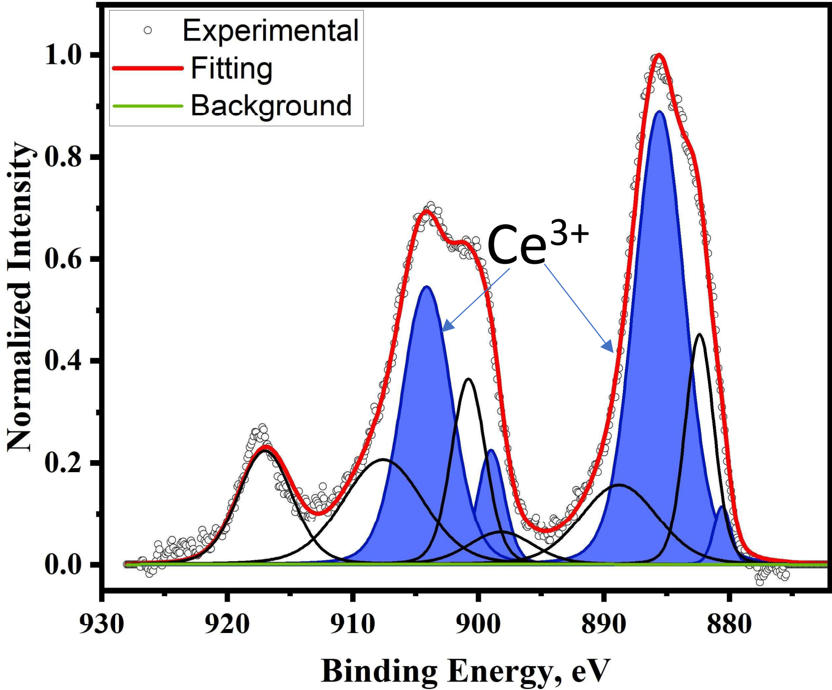


There is the presence of Tribofilm.

Source: Journal of Industrial and Engineering Chemistry Volume 94, 25 February 2021, Pages 105-121
J. Am. Ceram. Soc.,98[8] 2395–2402 (2015),
Systematic root cause analysis of ceria-induced defects during chemical mechanical planarization and cleaning. Journal of Manufacturing Processes, 127, 27-34.

Result

Chemistry Analysis of Ceria Defects



The main state of Cerium in the Ceria defects is **Ce^{3+} (56.5%),**

much higher than the Ce^{3+} from the Ceria abrasive defects (28%).

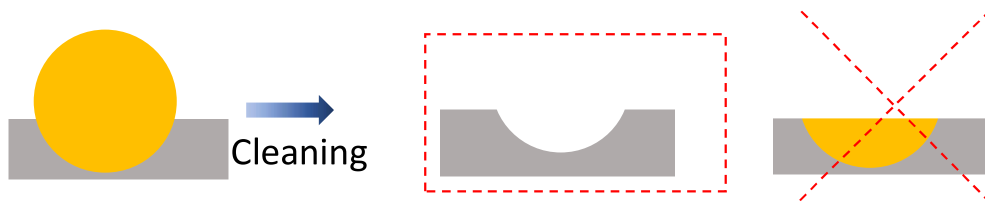
It can be due to the **small fragments (Case b)** and

Tribofilm (Case c).

Source: Systematic root cause analysis of ceria-induced defects during chemical mechanical planarization and cleaning. Journal of Manufacturing Processes, 127, 27-34.

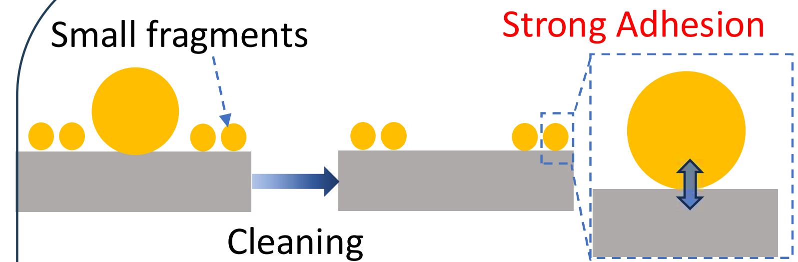
Summary

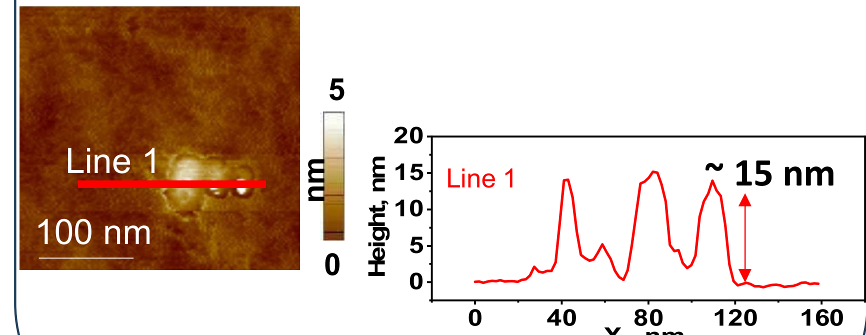
a. Ceria Remnants



The removal of embedded particles leave dents.

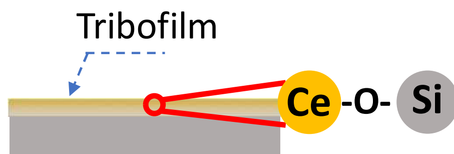
b. Ceria Fragments

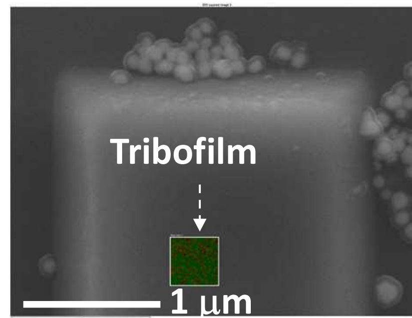




There are Ceria fragment on the film with the size of 10 -15 nm.

c.Tribofilm





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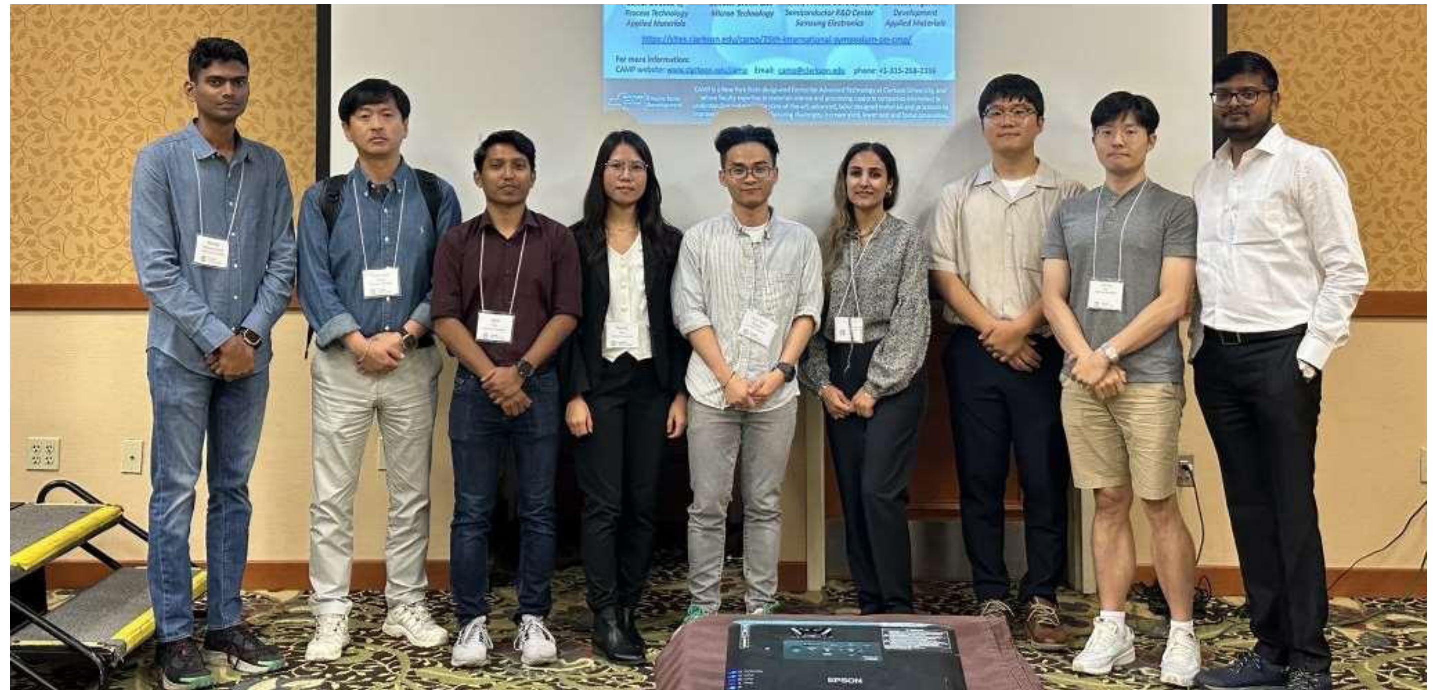

Thank you for your attendance

Any Question?